

EFFECTIVE THERMAL CONDUCTIVITY OF EPOXY MATRIX COMPOSITES FILLED WITH COCONUT COIR DUST

A Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of

B.TECH (MECHANICAL ENGINEERING)

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CERTIFICATE

This is to certify that the work in this thesis entitled *Effective Thermal Conductivity of Epoxy Matrix Composites Filled with Coconut Coir Dust* by **Soubhagya Ranjan Samal**, has been carried out under my supervision in partial fulfillment of the requirements for the degree of **Bachelor of Technology** in *Mechanical Engineering* during session 2010 - 2014 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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A C K N O W L E D G E M E N T

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ABSTRACT

The current work deals with numerical and experimental analysis of thermal conductivity of epoxy matrix composites filled with coconut coir dust. The numerical analysis proceeds with designing of 3-dimensional spheres-in-cube models with filler concentration ranging from 0-20% volume (approximately) and its thermal analysis. A commercially available software ANSYS is used as the tool for numerical analysis. The results are compared with effective thermal conductivity (K_{eff}) values obtained from experiment and other established models such as Rule-of-Mixture (ROM), Maxwell's model, and Aggarwal-Satapathy model. For experimental analysis coconut coir dust particle reinforced epoxy composites are fabricated using hand lay-up technique and the thermal conductivity values are measured with the UnithermTM model 2022 tester according to the ASTM standard E-1530. The present work reveals that the reinforcement of the coconut coir dust particles result in reduction of thermal conductivity of epoxy and upon increment of filler concentration the thermal conductivity reduces consistently. It is found that the reinforcement of 20 weight% of coconut coir dust particles, effective thermal conductivity of composite decreases substantially. With enhanced heat insulation capacity, these reinforced epoxy composites can find their application in insulated wall construction, food container, thermal flask and at such thermal insulation applications.

Key Words: Polymer matrix, composite, Epoxy, Coconut coir dust, effective thermal conductivity, FEM

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Chapter 1

Introduction

Chapter 1

INTRODUCTION

Composite Materials:

Composite Materials are reinforcement of two basic types of materials namely matrix and filler. The matrix acts as the building block and prevents any sort of external damage to the composite whereas the reinforcement of filler particles are aimed at improving its mechanical and thermal properties such as strength, ductility, stiffness, toughness, thermal conductivity etc. i.e. the matrix can be thought to be the parent material to which various alterations in physical and mechanical and thermal properties are brought about by addition of fillers. The constituents of composites do not retain their inherent properties in the composite. The primitive applications of composite materials are found where high strength and low weight are concerned. High strength, low density, high tensile strength at high temperatures, high toughness, and high creep resistance are a few properties of composites accounted for their wider use. Typically the matrix constitutes more than half of the volume fraction of the composite and fillers contribute less towards the volume but the change in properties is quite considerable. The strength of the composites varies with amount, distribution and type of filler material inclusion broadly.

Types of Composite Materials:

Based on the type of matrix material the composites are classified as

- a) Metal Matrix Composites (MMC)
- b) Ceramic Matrix Composites (CMC)
- c) Polymer Matrix Composites (PMC)

a) Metal Matrix Composites:

High strength, low co-efficient of thermal expansion, less weight are a few attributes which makes metal matrix composites preferable instead of metals in few applications . Carbide drills, automotive disk brakes, tank armor, cylinder linings of engines are a few applications.

b) Ceramic matrix Composites:

Ceramic fiber reinforcement into ceramic matrix forms ceramic matrix composites. Strongly increased toughness, extreme thermal shock resistance, very high ductility make ceramic matrix composites ideal for varied applications. During re-entry phase of space vehicles the heat shields are exposed to around 1500°C . Only Ceramic composites prove to be strong enough to sustain such high temperatures.

c) Polymer Matrix Composites:

The most commonly adopted matrix materials are polymers. Polymers are reinforced with fillers to improve strength, stiffness and thermal properties. The alteration in thermal conductivity due to addition of fillers gives conductive and insulating polymer composites which find a wide range of applications usually in electronic and food industries. Moreover the fabrication of polymer composite follows quite simple method being a reason for their popularity.

Polymer composites are used because overall properties of these composites are superior to those of the individual polymers. The elastic modulus is greater than that of the neat polymer but is not as brittle as ceramics.

Classification of polymer composites:

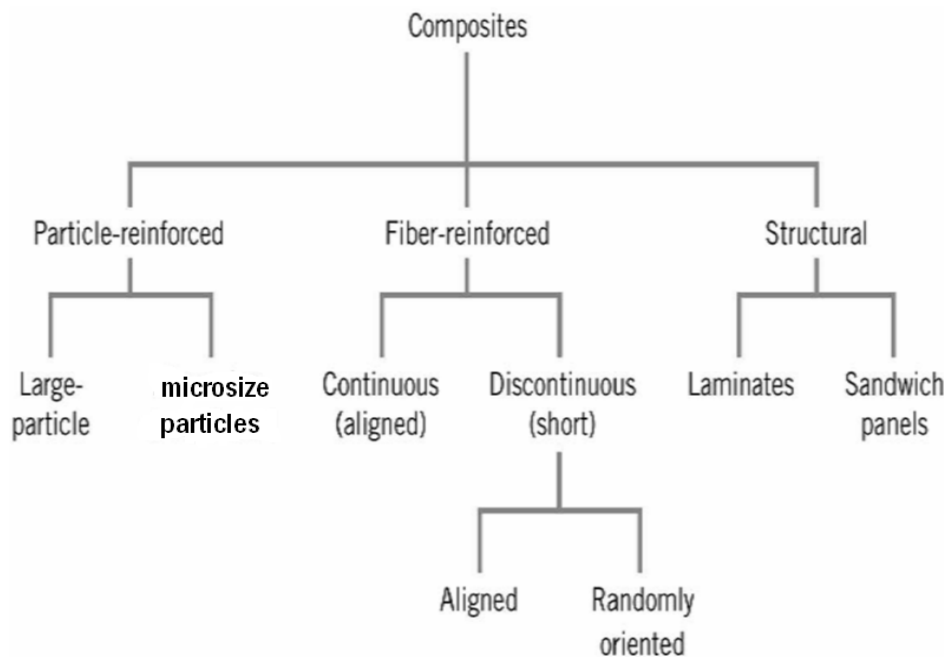


Fig. 1.1: Classification of composites based on reinforcement type

Polymer composites can be classified into following three groups on the basis of reinforcing material. They are:

- (a) Fiber reinforced polymer (FRP)
- (b) Particle reinforced polymer (PRP)
- (c) Structural polymer composites (SPC)

(a) Fiber reinforced polymer:

The fiber reinforced composites consist of fiber as filler material and polymers as matrices. The fibers used usually are glass, carbon, asbestos, basalt, aramid while sometimes easily available paper, wood are also used whereas epoxy, phenol formaldehyde resins, vinyl ester, poly-ester thermosetting plastic are commonly used polymer matrices. The fibers mainly contribute towards the strength of the composite. Fillers are often added to attain certain properties and ease the manufacturing process. It helps in reducing cost too. In need of a few specific mechanical properties like strength, elasticity these FRP are widely used.

(b) Particle reinforced polymer:

Ceramics, glass, mineral particles, Aluminum and amorphous materials even polymers are common particle reinforcements. The inclusion of particles enhances Young's Modulus and thus reduces ductility. High melting point, high strength-to-weight ratio, low ductility, electrical and thermal insulation are a few useful properties of ceramics. A few ceramics show excellent magnetic properties, some are piezo-electric and some even work as excellent superconductors at low temperatures. But due to brittleness ceramic particles are avoided for reinforcement in few cases. Carbon black particles reinforced in poly-isobutylene elastomeric polymer gives automobile tire material which is a type of particle reinforced polymer.

(c) Structural Polymer Composites:

Layers of materials held together by matrix gives structural polymer composites. Easy production, high productivity and low cost of production are the reasons why polymer matrices are used for structural composites. The high strength and high brittleness requirements for structural purposes are met by adding filler materials and fibers. These composites find their application in diverse fields from appliances to spacecraft.

Thermal conductivity modification of polymer matrices play pivotal rule for their applications in a few area of their applications. A lot of study has been carried out on various aspects of polymer composites but the study on their effective thermal conductivity analysis has been limited. The following study includes the variation of effective thermal conductivity of particulate filled polymer composites with concentration of filler.

Objective of the present Investigation

The objectives of this work are outlined as follows:

1. Fabricating coconut coir dust filled epoxy matrix composites to improve its thermal insulation abilities.
2. Determination of thermal conductivity (k_{eff}) of the fabricated polymer composites experimentally.
3. Use of Finite Element Method (FEM) to determine effective thermal conductivity values numerically.
4. Validation of the FEM analysis by measuring the thermal conductivity values experimentally.
5. Recommendation of these composites for suitable applications.

Chapter 2

Literature Review

Chapter 2

LITERATURE REVIEW

Literature review provides a brief background on various topics to be considered in this thesis and specifically specifies study of thermal properties of polymer composites. The topics include brief review on:

- 1) Particulate Reinforced Polymer Composites
- 2) Thermal Conductivity of Polymer Composites
- 3) Thermal Conductivity Models

(1) Particulate filled polymer composites:

Different mechanical properties like strength, corrosion resistance, wear resistance are reported to improve extensively upon addition of hard fillers like metals, ceramics.[1] Various kinds of metal reinforced polymers are widely applied in industries as heaters, high temperature thermal durability applications [3], electrodes [2], etc. Low density, ease of fabrication, corrosion resistance is few traits of engineering polymers [4]. Upon inorganic particle reinforcement polymer matrices develop stiffness improvement and cost reduction qualities opening scope for commercial applications [5]. Silica proves to be a useful filler particle to improve electrical, mechanical and thermal properties [6]. The effect of reduction of particle size is studied widely in [7]. Yamamoto et al. [8] studied effect of silica particle inclusions upon fatigue, tensile structure and corrosion resistance. Nakamura et al. [9] noticed increase in flexural and fatigue strength upon increment in specific surface area of particles reinforced.

(2) Thermal Conductivity of Polymer Composites

Hansen and Ho [10] worked on various aspects affecting thermal conductivity of polymer matrix composites. Heat transfer is observed to increase along particle orientation and reduce in a direction perpendicular to it. Aluminum particles, aluminum nitride, magnetic particles, copper and brass particles are commonly used, TiO₂, granite dust, coconut coir dust (natural fiber) are

a few usually used filler materials. Progelhof et.al [11] enlisted various models and methods for thermal analysis. Procter and Solc [12] took help of Nielsen model to study the variation of thermal conductivity of polymer matrix composites and debriefed their results and applicability of composites. Nagai [13] verified the Bruggeman model for Al₂O₃/epoxy matrix composite system and suggested its applicability as a good prediction theory for thermal conductivity of composites. The increment of thermal conductivity of Low Density Poly- Ethylene (LDPE) from 0.35W/mK to 50W/mK was reported by Griesinger et.al [14]. The effect of reinforcement of copper filler on poly-ethylene matrix composites was studied by Tavman [15] while Sofian et al. [45] analyzed change of thermal properties like thermal diffusivity, thermal conductivity upon reinforcement of metal(iron, zinc, copper, bronze) particles in High Density Poly-Ethylene (HDPE) composites. Upon 16% of metal filler reinforcements moderate increase in thermal conductivity was observed. Substantial improvement in thermal conductivity upon metal particle reinforcement was investigated by Mamunya et al. [16]. The interconnectivity of filler particles and their effect on thermal conductivity was studied by Weidenfeller et al. [17]. He prepared PP (Poly-Propylene) by extrusion and injection molding process with reinforcement of different commercially available fillers with a wide range of filler concentration. His work surprisingly produced results showing elevation of thermal conductivity of PP from 0.27 to 2.5W/mK with addition of 30 volume% talc as filler .To the contrary inclusion of copper as filler(with thermal conductivity around 40% more than that of Talc) with equal volume fraction improved thermal conductivity to only 1.25W/m-K . The effect of shape factor of reinforced fillers on thermal conductivity was noticed in the study by Tekce et.al [18]. Patnaik et.al [19] pointed out a correlation existing among effective thermal conductivity and effective wear resistance between particulate filled polymer composites.

(3) On Thermal Conductivity Models

Various models are suggested to study and predict effective thermal conductivity of multi-phase (especially two-phase) mixtures. The models find their validation in various polymer composites. The arrangements of materials in either parallel or series in two

composites with two components governs the variation of thermal conductivity.

The variation of effective thermal conductivity for parallel conduction model can be represented as:

$$k_c = (1 - \phi)k_m + \phi k_f \quad (2.1)$$

Where K_c , K_m , K_f denote the thermal conductivity values of the polymer composite, the parent material (matrix) and the filler respectively and ϕ represents concentration (% volume fraction) of filler.

For the series conduction model the thermal conductivity varies according to the relation :

$$\frac{1}{k_c} = \frac{1-\phi}{k_m} + \phi/k_f \quad (2.2)$$

The correlations among thermal conductivity and volume fraction presented by equations (2.1) and (2.2) are based on Rules of Mixture (ROM). Tsao [20] worked on establishing a relationship between thermal conductivity of two-phase mixture to that of individual constituents and the parameters signifying the spatial distribution of different existing phases. Cheng and Vachon [21] suggested a modification to Tsao's [22] model with an assumption that discontinuous phase follows parabolic distribution in continuous phase which discarded the requirements of additional parameters. Agari and Uno[23] model took series and parallel conduction mechanism into account. The model provides the following relationships for thermal conductivity of

Composites.

$$\text{Log}(K_c) = \phi_c * 2 \log(K_f) + (1-\phi) \log(c1 K_f)$$

The thermal conductivity of randomly distributed homogenous spheres in a homogenous medium is represented by Maxwell's correlation.

$$\frac{k_{eff}}{k_p} = \left(\frac{k_f + 2k_p + 2\phi_f(k_f - k_p)}{k_f + 2k_p - \phi(k_f - k_p)} \right) \quad (2.3)$$

The above model very well describes the relationships at lower filler concentrations but fails to provide effective results at higher filler concentrations when the filler contents increase and conductive chains start to form. The above models have not taken the filler shape and size into concern. On that basis the following model has been proposed to effectively describe the relationship between thermal conductivity and volume fraction with usual notations.

$$k_{eff} = \frac{1}{\frac{1}{k_p} - \frac{1}{k_p} \left(\frac{6\phi_f}{\pi} \right)^{\frac{1}{3}} + \frac{4}{\left(k_p \left(\frac{4\pi}{3\phi_f} \right)^{\frac{2}{3}} + \left(\frac{2\phi_f}{9\pi} \right)^{\frac{1}{3}} 2\pi(k_f - k_p) \right)}$$

Chapter 3

Materials and Methods

Chapter 3

MATERIALS AND METHODS

The materials used for fabrication of composites for experimental analysis and methods to determine thermal conductivity is described in this chapter. The details of characterization and thermal conductivity tests which the composite samples are subjected to are described. The numerical methodology related to the determination of thermal conductivity based on finite element method is also presented in this chapter of the thesis.

MATERIALS

Matrix Material:

The matrix consists of Epoxy resin(LY 556) (belongs to Epoxide family). Its chemical name is Bisphenol-A-Diglycidyl-Ether. Mixtures of Epoxy resin and corresponding hardener 10:1 weight ratio as suggested with varying filler concentration are prepared. Ciba Geigy India Ltd supplies the required epoxy and hardener. Epoxy is a commonly used polymer matrix with a low thermal conductivity of 0.363W/mK.

Filler Material:

Coconut coir dust is a widely available natural fiber used as a filler material. It is widely used for floor mats, door mats, brushes, mattresses etc. White coir is used for finer brushes, string, rope, fishing nets etc. Its thermal conductivity and density values are 0.1036 W/mK and 0.75 gm/cc respectively.

Composite Fabrication:

Mixtures with epoxy resin (LY 556) and corresponding hardener (HY951) in a weight ratio of 10:1 by as recommended are prepared to fabricate the composite. Coconut coir dust with an average particle size of 100-200 μm are filled in epoxy resin matrix (density 1.1 gm/cc) to prepare the composites. The meticulously prepared mixture is then poured into the glass tubes. The glass tubes are coated with wax and thin film of

silicone-producing agent to prevent the mixture from sticking to the tube.

The composites are cast in cylindrical specimens (dia. 9 mm, length 120 mm). Composites of four different compositions (with 5,10,15,20 weight % of coconut coir dust respectively) are fabricated. The prepared castings are left at room temperature for about 24-30 hours. The tubes are firmly broken to collect samples.

Serial no.	Weight fraction of filler	Mass of filler(in g)	Mass of epoxy(in g)	Mass of Hardener(in g)
1	0	0	9.09	0.909
2	5	0.5	8.63	0.863
3	10	1	8.18	0.818
4	15	1.5	7.72	0.772
5	20	2	7.27	0.727

Table 3.1: List of compositions of particulate filled composites fabricated by hand-lay-up technique

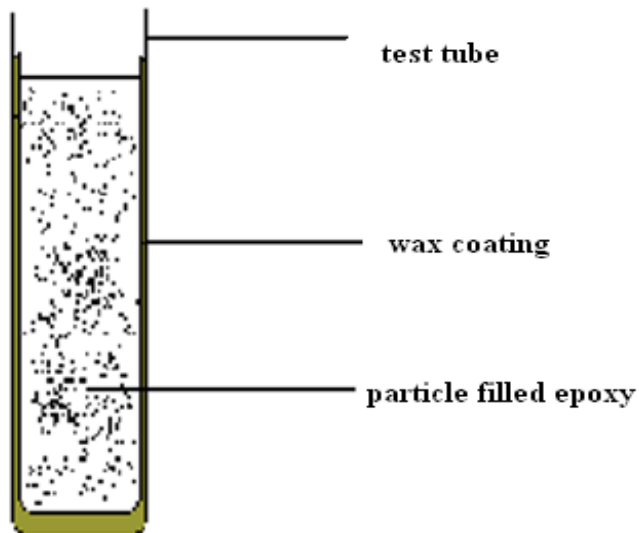


Fig. 3.1 Preparation of particulate filled composites by hand-lay-up technique

THERMAL CONDUCTIVITY CHARACTERIZATION

Experimental Determination of thermal Conductivity:

Thermal conductivity of a various materials including polymers, metals, ceramics, glasses, rubber can be effectively measured by UnithermTM 2022 Model for which a relatively small sample is to be fabricated. Special containers for paste and liquid are provided. With multi-layer technique thermal conductivity of thin film layers can also be measured. The tests follow ASTM E-1530 Standard.

Two polished surfaces subjected to optimal compressive load hold the sample in between. The lower surface acts as a calibrated heat flow transducer. Due to an axial temperature gradient heat flow occurs from upper surface to lower surface through the sample. The heat flow transducer gives value of heat flux whereas the temperature difference is measured the temperature values. Thermal conductivity can be calculated using these values and the thickness of the sample. Temperature of the surfaces on either side of the sample is measured using temperature sensors.



Fig. 3.2 Estimation of Thermal Conductivity Using Unitherm™ Model 2022

Thermal conductivity represents heat flow within a system at a particular temperature gradient. The one-dimensional heat flow in a system can be represented by equation 3.1:

$$Q=KA(T_1-T_2)/X \quad (3.1)$$

In Unitherm™ 2022 model, the heat flux transducer measures the Q value and the temperature difference can be obtained between the upper plate and lower plate from the temperatures given by temperature sensors. With the thickness and cross-sectional area of the sample known thermal conductivity can be calculated using Equation 3.1.

Numerical Analysis: Finite Element Method (FEM) and ANSYS:

FEM is used for solving a variety of complex engineering problems with different boundary conditions. FEM proves to be a very useful tool for designing and. The basic principle of FEM is the dis-integration of physical domain into number of subdomains (elements) and stepwise analysis of the elements. It helps FEM to reduce the problem to that of a finite number of unknowns.

FEM deals with a large variety of engineering problems e.g. heat transfer, stress analysis, fluid flow etc. ANSYS is an usually used all-purpose FEM package for numerically solving a wide variety of mechanical problems involving structural analysis, heat transfer, fluid problems etc.

Chapter 4

Results and Discussion

Chapter 4

RESULTS AND DISCUSSION

PHYSICAL CHARACTERIZATION

THERMAL CONDUCTIVITY CHARACTERIZATION

Description of the problem

The study of effective properties of composite materials upon reinforcement of filler materials is of great importance for application of composite materials. The microstructure of composite controls the properties of composites in an extended manner. Microstructure represents the shape, size, distribution and orientation of the reinforcing inclusions in the matrix. Of all the properties thermal conductivity plays a vital role as far as application of polymer composites in various fields e.g. electronic packaging, food packaging, thermal insulation walls, thermal coating, are concerned. Using the finite-element program ANSYS, thermal analysis in form of a heat transfer model is carried out for the conductive heat transfer through the composite body. The problem consists of three-dimensional physical models with spheres-in-a-cube lattice array similar to a unit cell of a composite. Furthermore, the effective thermal conductivities of these epoxy composites filled with coconut coir up to about 23% by volume is numerically determined using ANSYS.

Assumptions

In the analysis of the ideal case it will be assumed that

- 1) The filler particles are homogenously distributed.
- 2) The thermal contact resistance between matrix and filler is negligible.
- 3) The lattice is free of voids and imperfections.
- 4) The composite is crystalline i.e. the filler distribution is periodic.

Numerical Analysis

In the model adopted for numerical analysis the temperature of the face ABCD is taken as T_1 ($=100^\circ\text{C}$) and the heat transfer coefficient of ambient for convection is assumed to be $25\text{ W/m}^2\text{-K}$ at ambient temperature of 25°C . The heat flow direction is represented in the following figure (Fig 4.1). All other faces are insulated and thus the heat flow is one-dimensional. The temperatures at nodes on boundary and on the interior are unknown. Finite-element analysis by ANSYS calculates these temperatures.

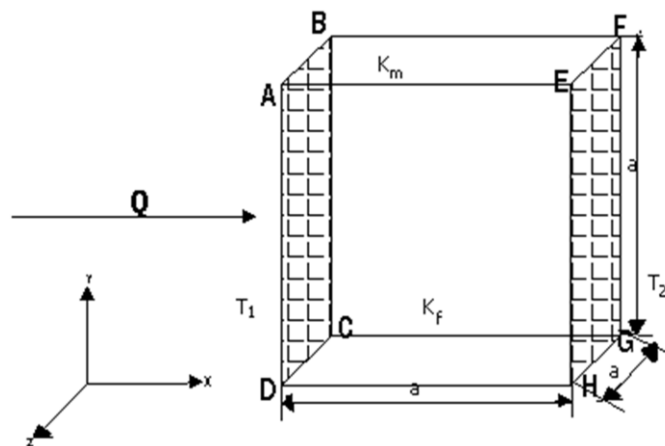


Fig.4. 1 Boundary conditions

The numerical analysis results are as follows

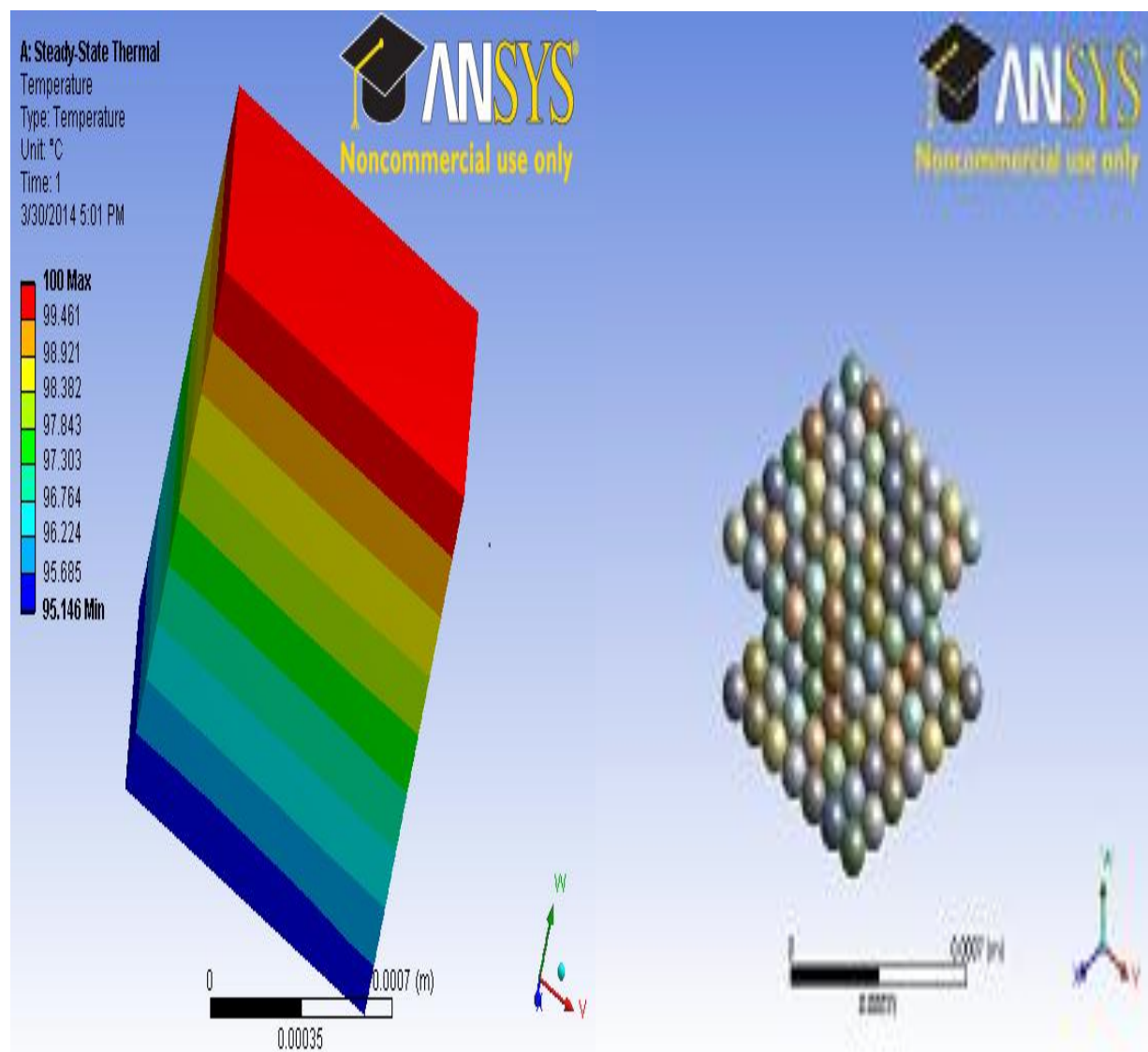
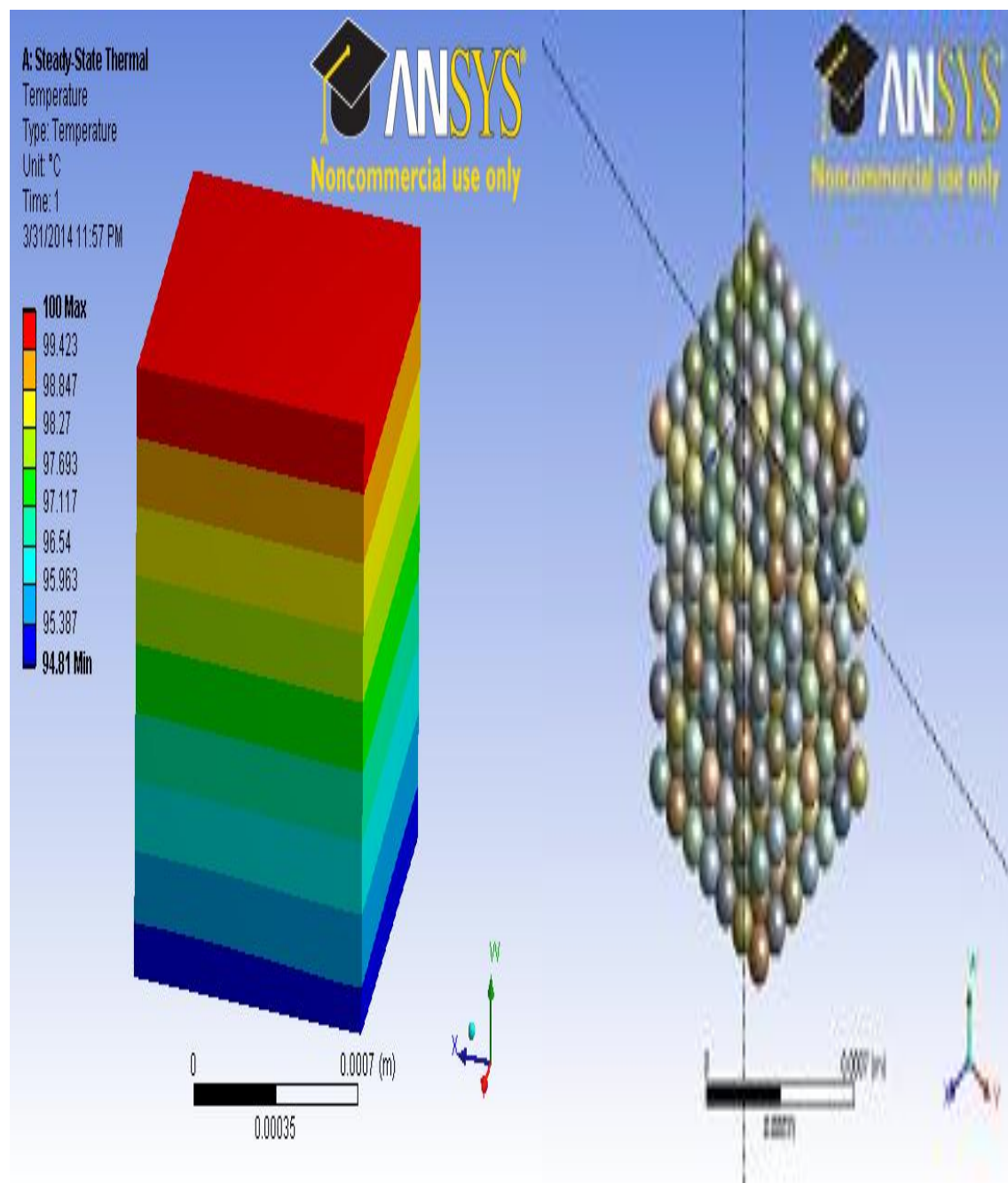


FIG. 4.2(A)

**Fig 4.2(B)**

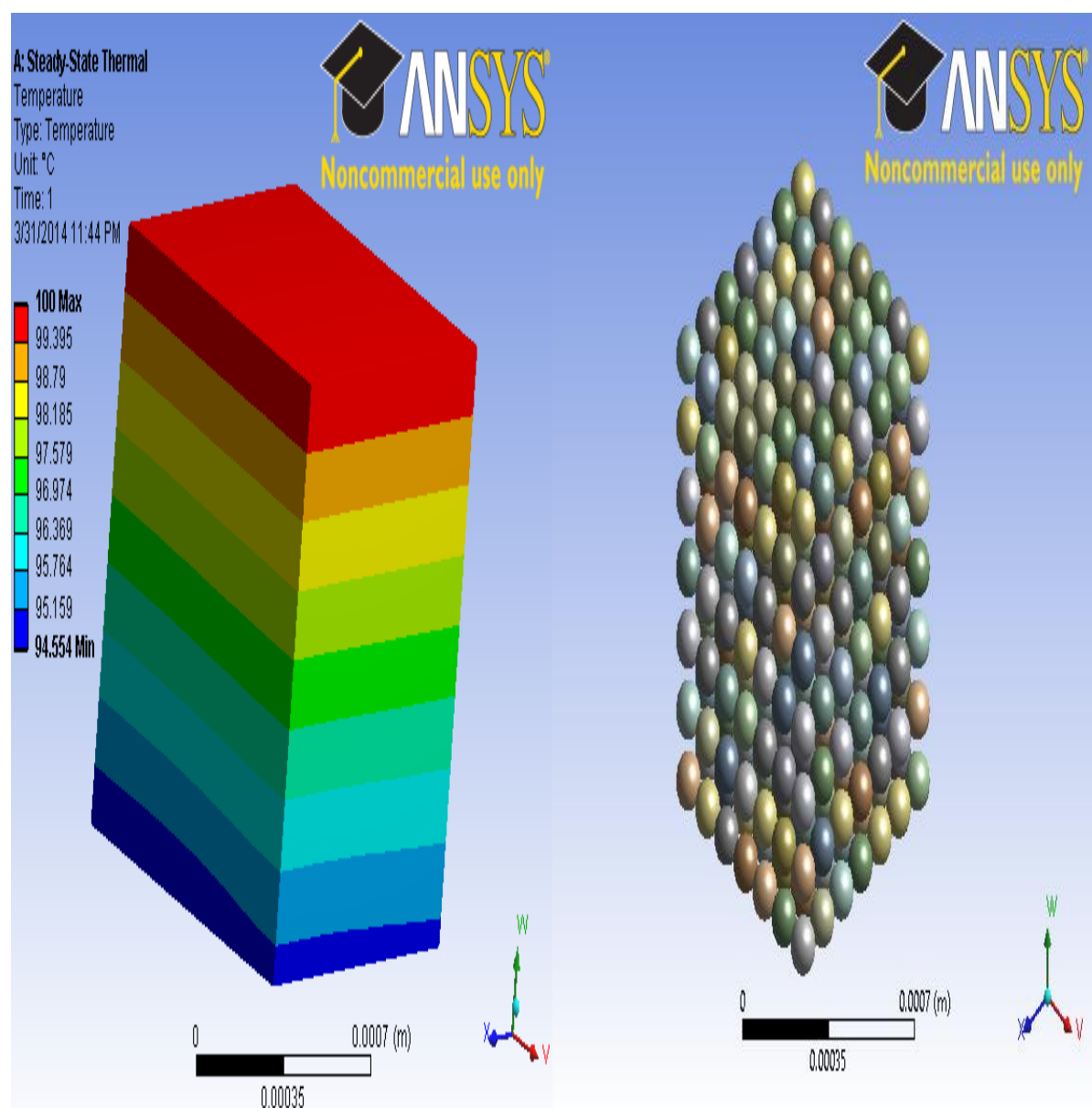


FIG. 4.2 (C)

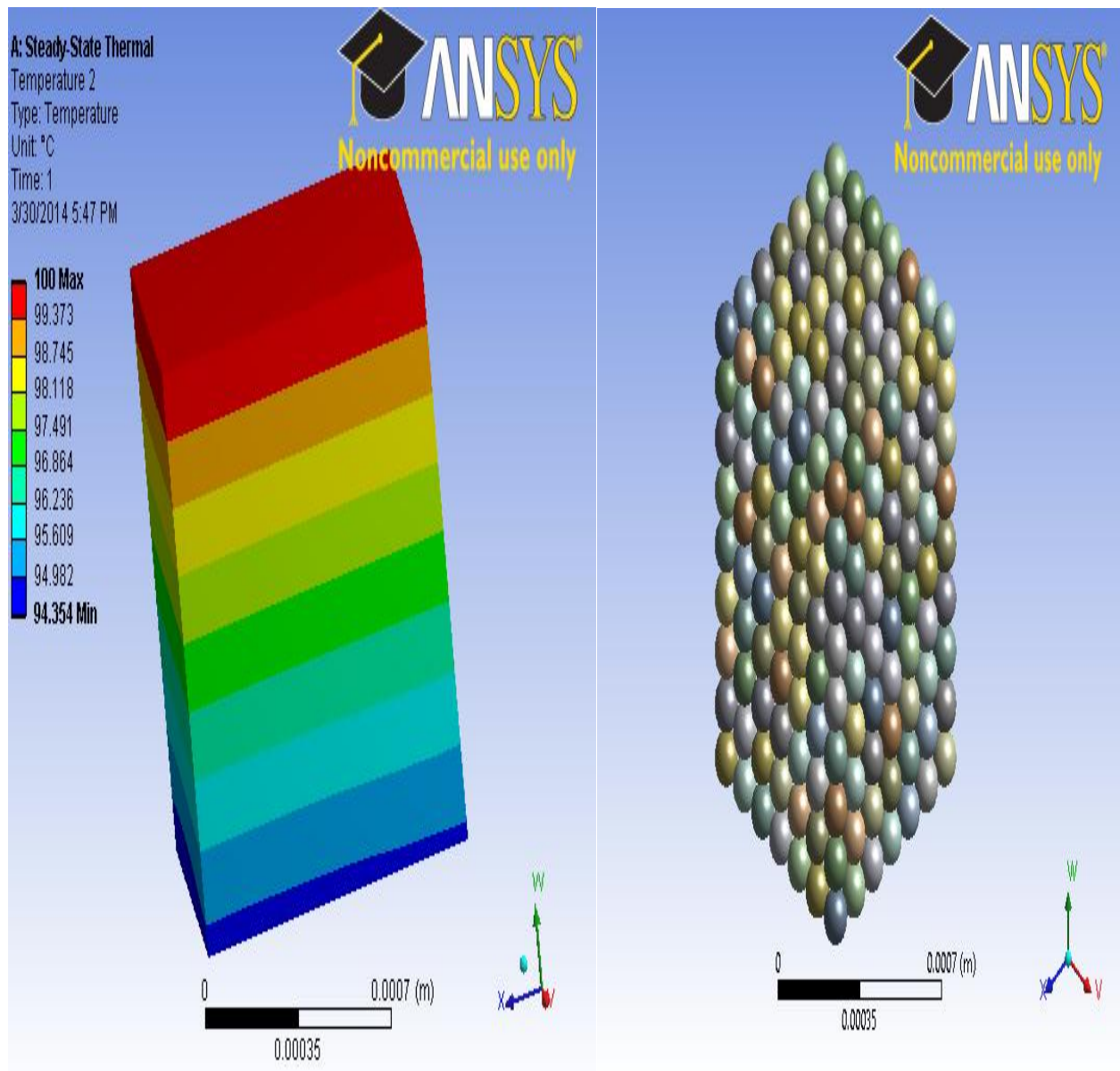
**FIG.4.2 (D)**

Fig. 4.2 Temperature profiles for Coconut coir filled epoxy composites with particle concentration of (a) 5.13vol% (b) 12.82vol% (c) 17.93 vol% (d) 23.08 vol% respectively

Serial no.	Volume Fraction(ϕ) (%)	K_{eff} (Exp) (W/mK)	K_{eff} (FEM) (W/mK)	K_{eff} (Model) (W/mK)	K_{eff} (ROM) (W/mK)	K_{eff} (Maxwell) (W/mK)
1	0	0.360	0.360	0.363	0.363	0.363
2	5	0.270	0.361	0.228	0.323	0.334
3	10	0.203	0.345	0.195	0.290	0.317
4	15	0.183	0.328	0.171	0.263	0.302
5	20	0.161	0.314	0.152	0.241	0.288

Table 4.1 Thermal conductivity for composites obtained from FEM, Experiment, and Models

Serial no.	Vol %	FEM(%)	Model(%)	ROM(%)	Maxwell(%)
1	0	0	.83	.83	.83
2	5	33.7	-15.5	19.6	23.7
3	10	70	-3.9	42.85	56.15
4	15	79.23	6.55	43.7	65
5	20	95	-5.5	49.68	78.8

Table 4.2 Percentage errors associated with K_{eff} values w.r.t. the experimental values

The variation as per the above tabulation is plotted as follows.

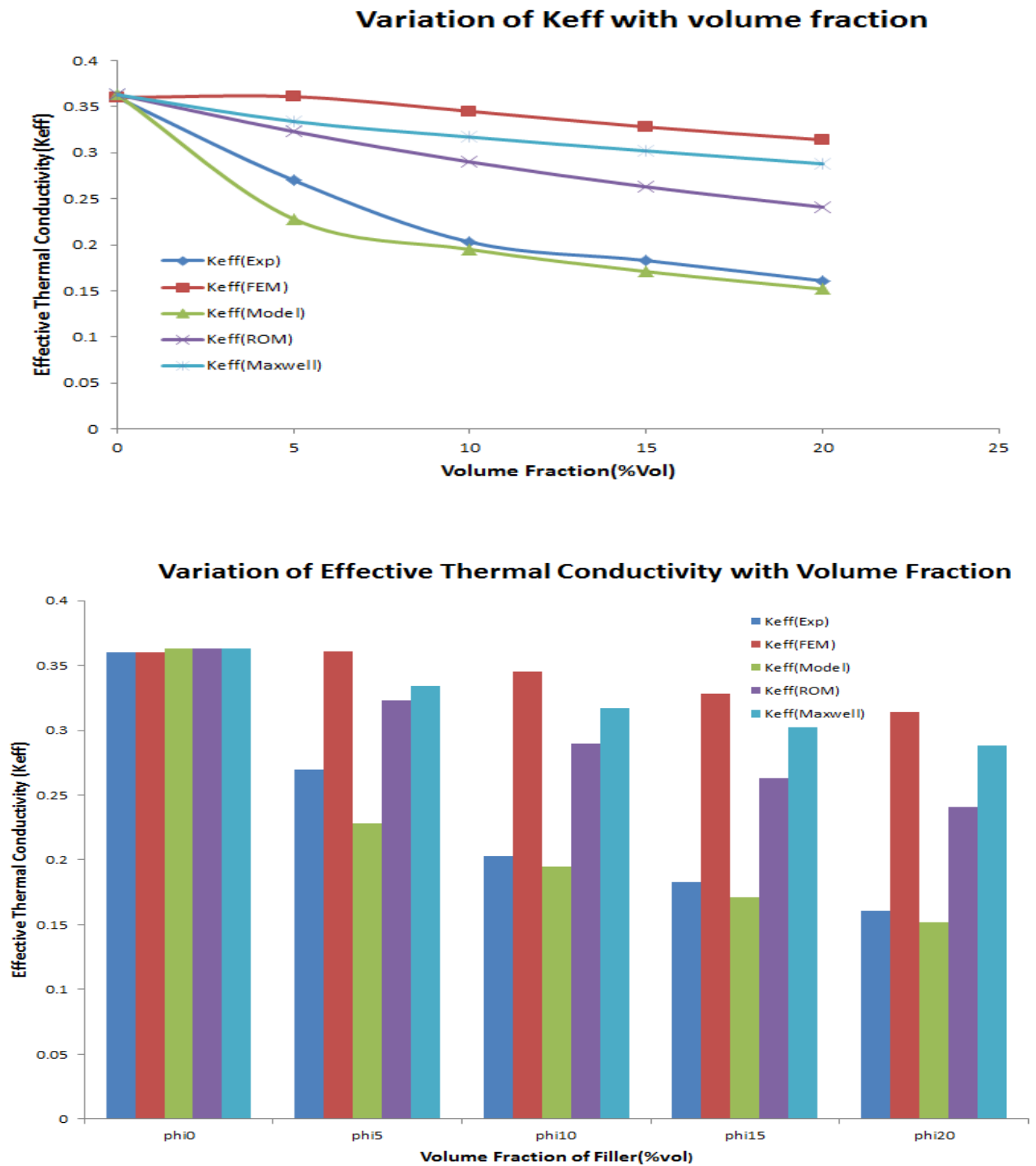


Fig. 4.3 showing the variation of effective thermal conductivity

Thermal conductivity of spheres-in-cube models are estimated numerically with the concentration of filler ranging 0-20% (approximately). The results of the numerical analysis show temperature profiles along the heat flow direction with particulate concentrations varying as 5.13, 12.82, 17.95, 23.08 volume %.

The study verifies effectiveness of finite element study by comparing the numerical analysis results with experimental and theoretical results. The study reveals the applicability of FEM as thermal conductivity values obtained from FEM are in acceptable occurrence with that from experimental analysis for filler concentrations from about 0 to 20 volume % but deviates at higher concentrations. Incorporation of coconut coir dust results in substantial reduction of thermal conductivity of epoxy resin effectively.

Chapter 5

Conclusions

Chapter 5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

Conclusions

This analytical, numerical and theoretical investigation on thermal conductivity of Coconut coir dust filled epoxy matrix composites have led to the following conclusions:

- The Experimental values and the values given by accepted model are in close occurrence and at higher concentrations of filler the values are almost equal. Rule-of-mixture (ROM) and Maxwell models provide acceptable results at lower concentrations but upon increment in filler concentration those models are not acceptable.
- The effective thermal conductivity reduces consistently with increment of coconut coir concentration and reduces significantly to 50% at 15% volume fraction and 44.4% at 20% volume fraction and thus coconut coir can be effectively used as filler..
- The fabrication of coconut coir filled epoxy composites is possible as the composite can be effectively used in various fields.
- The use of FEM (Finite Element Method) gives reliable results as the thermal conductivity values obtained are in agreement with that of experimental values.
- These classes of polymer composites can find their application in field of electronic packaging, food packaging, electrical cable insulation, thermo-flask, thermal insulated walls and other insulation applications.

Scope for future work

This work leaves a wide scope to explore and study various fields regarding thermal characteristics of polymer composites. Some recommendations for future research include:

- Effect of filler shape and size on effective thermal conductivity of the composites
- Exploration of new fillers for development of thermal insulation materials

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